US009174165B1

(12) **United States Patent**
Dube

(10) **Patent No.: US 9,174,165 B1**
(45) **Date of Patent: Nov. 3, 2015**

(54) **ACIDIC GAS REMOVAL USING DRY SORBENT INJECTION**

(71) Applicant: **ALSTOM Technology Ltd**, Baden (CH)

(72) Inventor: **Sanjay Kumar Dube**, Knoxville, TN (US)

(73) Assignee: **ALSTOM Technology Ltd**, Baden (CH)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/471,422**

(22) Filed: **Aug. 28, 2014**

(51) **Int. Cl.**

B01D 53/50	(2006.01)
B01D 53/62	(2006.01)
B01D 53/68	(2006.01)
C01D 7/07	(2006.01)
B01D 53/40	(2006.01)
B01D 53/81	(2006.01)

(52) **U.S. Cl.**
CPC ***B01D 53/40*** (2013.01); ***B01D 53/508*** (2013.01); ***B01D 53/62*** (2013.01); ***B01D 53/685*** (2013.01); ***B01D 53/81*** (2013.01); *B01D 2253/112* (2013.01); *B01D 2258/0283* (2013.01)

(58) **Field of Classification Search**
CPC B01D 53/50; B01D 53/501; B01D 53/62; B01D 53/68; C01D 7/07
USPC 423/244.08
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

276,990 A		5/1883	Gaskell, Jr. et al.	
574,089 A		12/1896	Hawliczek	
3,647,365 A		3/1972	Saeman	
3,846,535 A		11/1974	Fonseca	
4,385,039 A		5/1983	Lowell et al.	
4,452,766 A	*	6/1984	Pike	B01D 53/501 423/166
4,459,272 A		7/1984	Krieg et al.	
7,910,079 B2	*	3/2011	Anttila	B01D 53/502 423/220
8,206,670 B2	*	6/2012	Detournay	C01D 7/07 423/244.07
8,916,118 B2	*	12/2014	Escudero	B01D 53/501 423/225
2006/0286011 A1	*	12/2006	Anttila	B01D 53/502 422/168
2013/0156673 A1	*	6/2013	Nagayasu	B01D 53/75 423/243.08

FOREIGN PATENT DOCUMENTS

FR	2273765 A1	*	1/1976	....	C01D 7/07

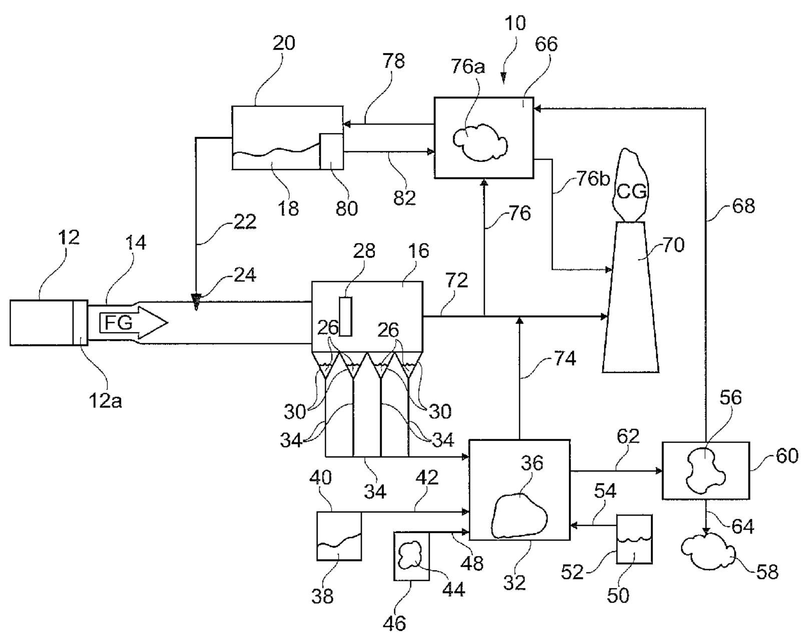
* cited by examiner

Primary Examiner — Timothy Vanoy
(74) *Attorney, Agent, or Firm* — Rita D. Vacca

(57) **ABSTRACT**

A system and method for desulfurization or acidic gas removal from a hot flue gas is provided that uses a dry sorbent injection technology with downstream sorbent reproduction based on a dual-alkali process. As such, lime and flue gas carbon dioxide are used in a process to produce the dry sorbent, sodium bicarbonate.

15 Claims, 3 Drawing Sheets



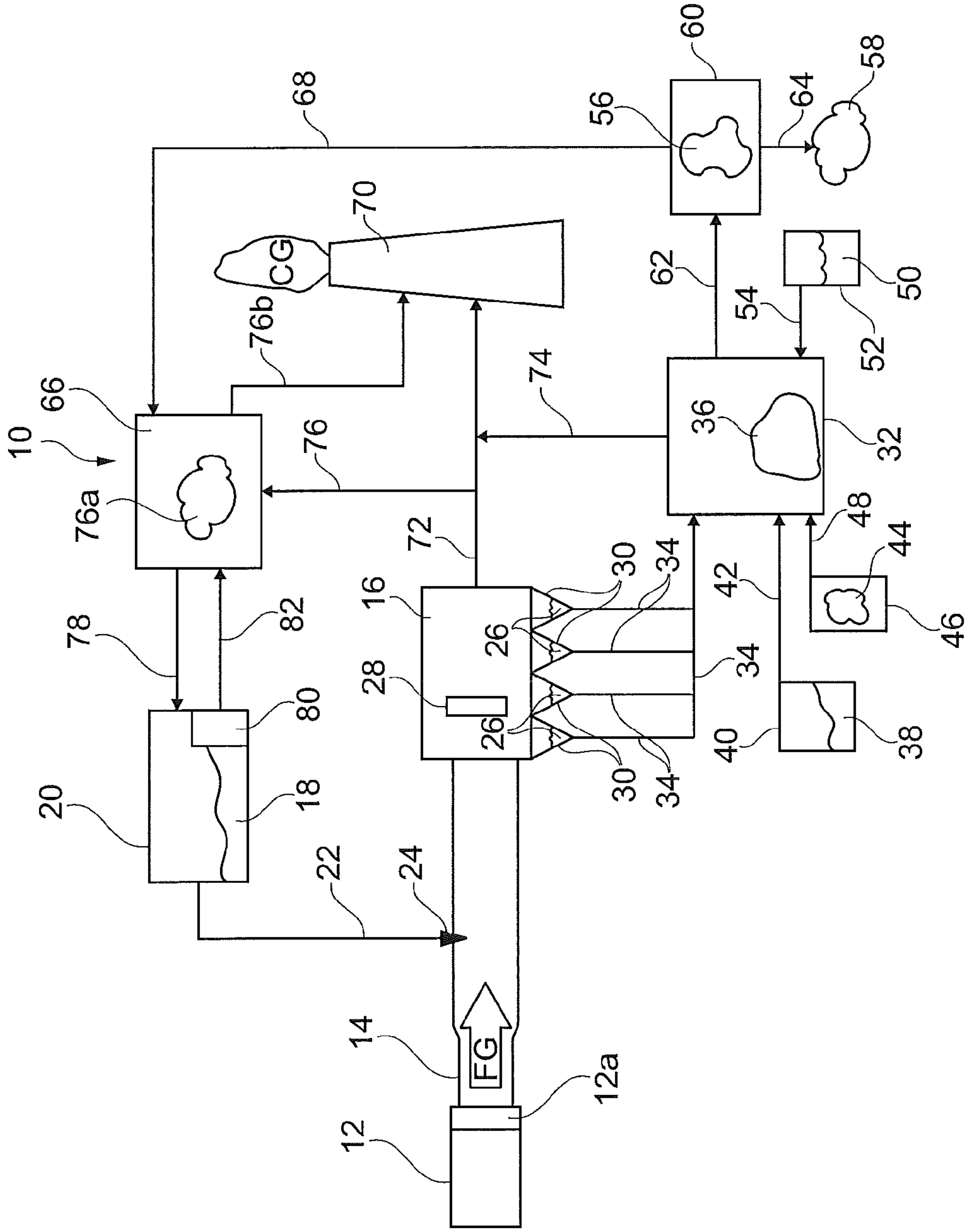

10
12
12a
14
FG
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
CG
72
74
76
76a
76b
78
80
82

Fig. 1

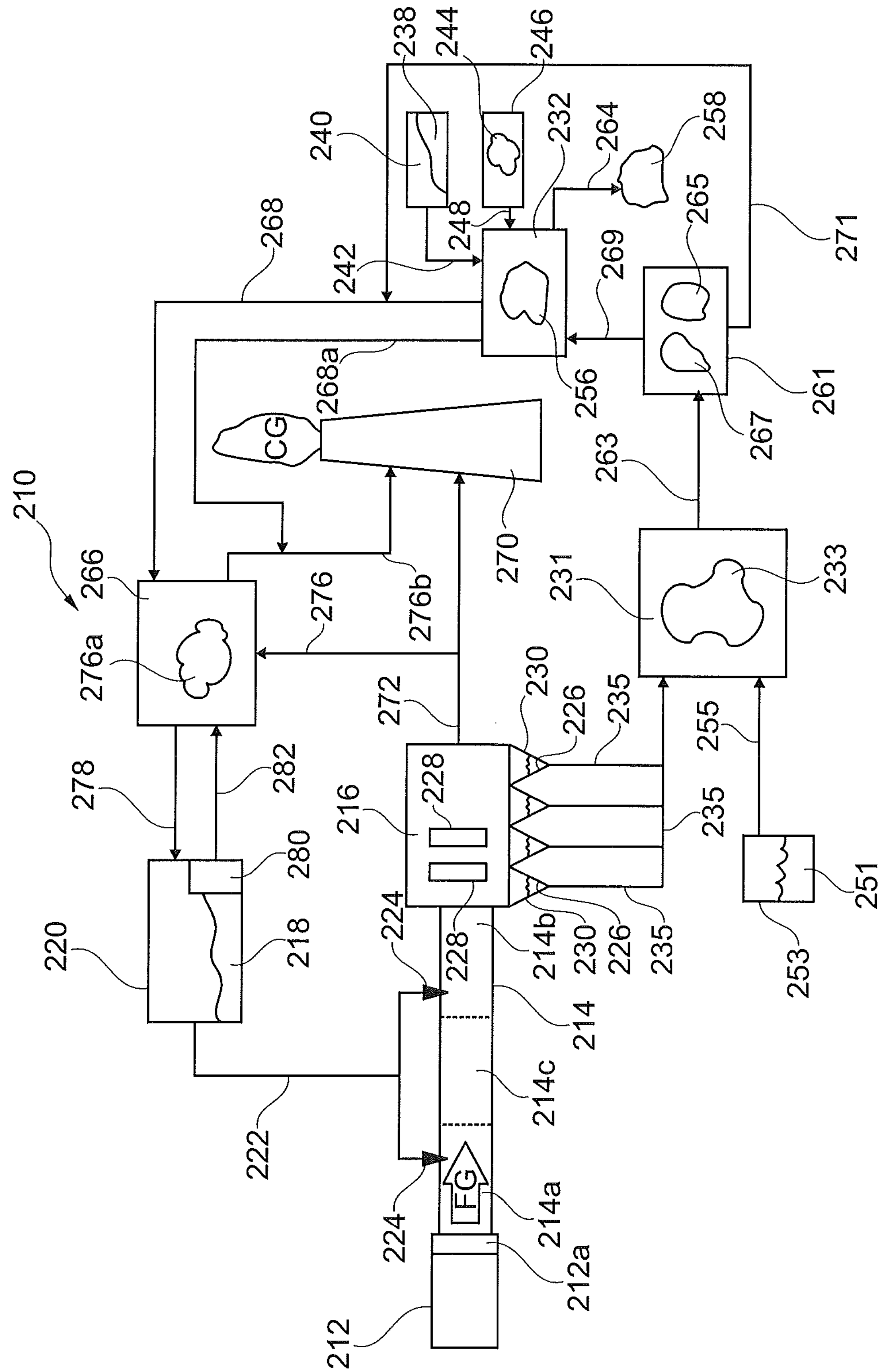

210
212
212a
214
214a
214b
214c
216
218
220
222
224
226
228
230
231
232
233
235
238
240
242
244
246
248
251
253
255
256
258
261
263
264
265
266
267
268
268a
269
270
271
272
276
276a
276b
278
280
282
FG
CG

Fig. 2

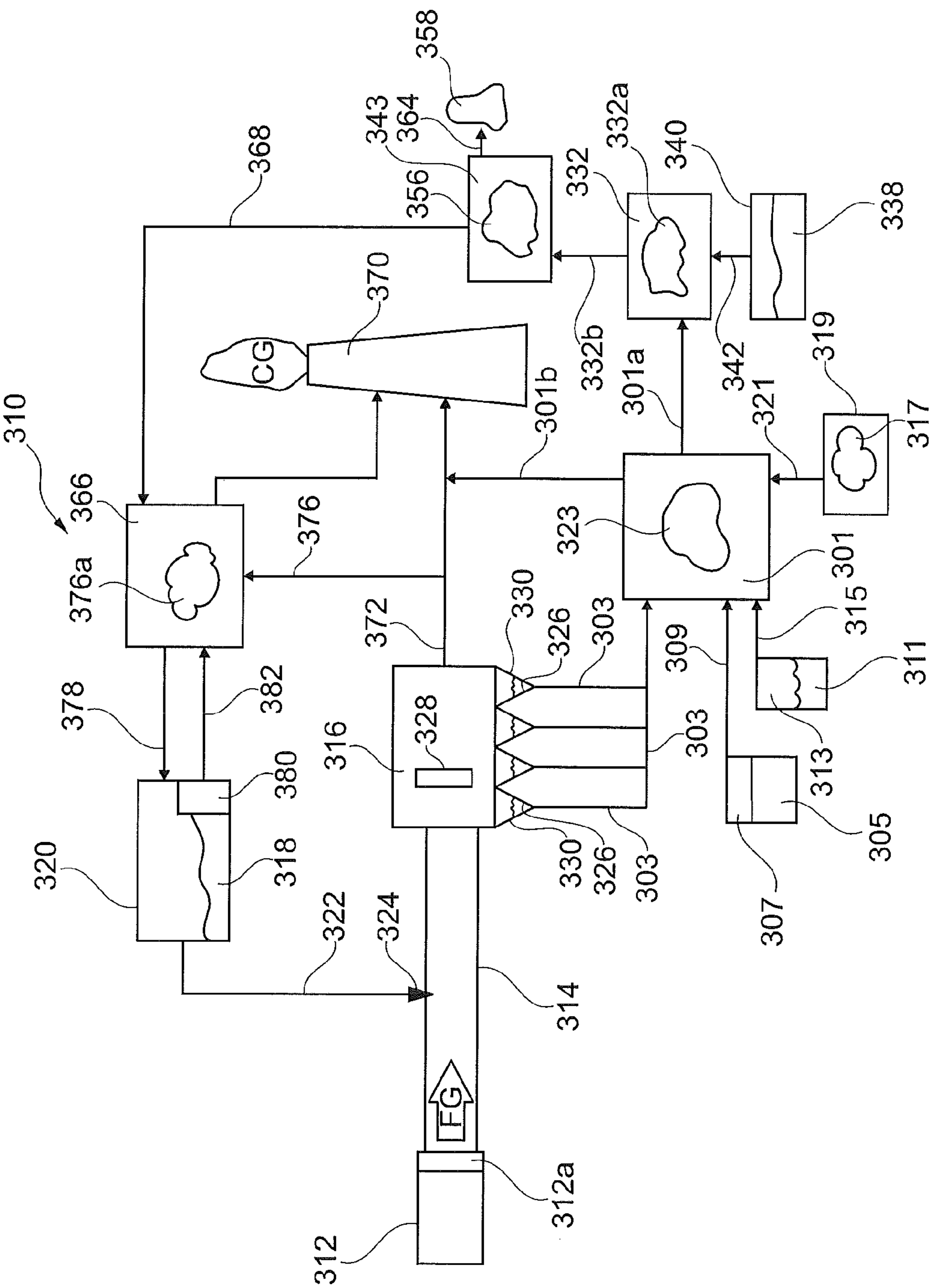

310
366
376a
376
372
320
378
382
380
318
322
324
314
FG
312
312a
316
328
330
326
303
309
305
307
313
311
315
301
323
317
319
321
301a
301b
370
CG
368
356
343
364
358
332
332a
332b
340
338
342

Fig. 3

ACIDIC GAS REMOVAL USING DRY SORBENT INJECTION

FIELD OF THE DISCLOSURE

This disclosure provides a system and method for desulfurization or acidic gas removal from a hot flue gas using a dry sorbent injection technology based on a dual-alkali process. More specifically, the disclosure provides a system and method for desulfurization or acidic gas removal from a hot flue gas using a dry sorbent injection technology based with downstream sorbent reproduction using lime and flue gas carbon dioxide.

BACKGROUND OF THE DISCLOSURE

The conventional technique for commercial production of sodium bicarbonate dissolves soda ash in a spent reaction liquor from a prior reaction, consisting of water containing small quantities of dissolved soda ash and sodium bicarbonate. The solution is then carbonated to precipitate crystals of sodium bicarbonate. The sodium bicarbonate crystals are separated from the liquor and dried to yield highly purified, high density crystals. Disadvantages of the conventional method are that the procedure requires several steps, and necessitates using of separation equipment, drying of the product, and handling of large volumes of liquids.

Sodium bicarbonate may also be produced by various dry carbonation techniques. In U.S. Pat. Nos. 276,990 and 574,089, a sodium bicarbonate product is formed by placing hydrated soda ash in a revolving cylinder and then introducing carbon dioxide into the cylinder. Both patents teach reaction times of approximately five to six hours.

U.S. Pat. No. 3,647,365 teaches a process in which hollow sodium bicarbonate beads of low density are prepared in a multistage reactor from hydrated soda ash, small amounts of water and carbon dioxide. This process requires several steps and must proceed slowly, with carbonation times exceeding one hour and drying times taking up to eight hours. Further, the soda ash must first be hydrated in a separate step and the reaction must occur at a temperature above 95.7° F. to achieve a commercially acceptable reaction rate.

More recently, U.S. Pat. No. 4,459,272, discloses a process for the preparation of sodium bicarbonate by the reaction of a solid, particulate sodium carbonate-containing material with liquid water in a carbon dioxide-rich atmosphere. The particulate mass is mixed in an internally agitated or externally rotated or vibrated reactor with the water and carbon dioxide. The reaction is carried out at temperatures from 125° F. to 240° F. under atmospheres containing from 20% to 90% carbon dioxide by volume. The process is carried out under reduced water vapor partial pressures to promote evaporation of water from the surfaces of the reacting carbonate particles, and to maintain high carbon dioxide partial pressures in the reactor atmosphere. Products formed by the process have apparent bulk densities as high as 50-60 lbs/ft^3.

Each of the previously described dry carbonation techniques is subject to particular disadvantages. In each process, the carbon dioxide concentration must be high and the reaction temperature must also be high, or the reaction rate is prohibitively low. None of these methods can produce sodium bicarbonate at low temperatures and low carbon dioxide concentrations, at commercially acceptable reaction rates.

Sodium bicarbonate has also been produced, as well as utilized, in dry sorbent injection processes for removing sulfur dioxide emissions from the combustion gases of fossil fuel fired burners. Such techniques have commanded considerable attention recently, particularly since they present the lowest "first cost" alternative for removing potentially dangerous sulfur dioxide from flue gases. Sodium bicarbonate has been demonstrated to be a very effective sorbent for dry sorbent injection processes. However, the cost of pharmaceutical grade sodium bicarbonate, as currently produced, is a major drawback to its use for such purpose.

U.S. Pat. Nos. 3,846,535 and 4,385,039 disclose methods for regenerating sodium bicarbonate from sulfate-containing solid waste formed by dry sorbent injection with sodium bicarbonate. According to U.S. Pat. No. 3,846,535, a regeneration step is accomplished by forming an aqueous solution of the sodium sulfate containing waste, and treating such solution with ammonium bicarbonate to precipitate sodium bicarbonate. The sodium bicarbonate is then separated, dried and recycled for further use. According to U.S. Pat. No. 4,385,039, a regeneration step involves dissolving the solid desulfurization reaction product in a basic liquor, which contains borate ions and/or ammonia. Carbonation of this liquor results in a sodium bicarbonate precipitate. Each of these disclosed processes suffer from the use of complicated and capital-intensive equipment and solution operations.

An improved process for the production of sodium bicarbonate for use in dry flue gas desulphurization processes that does not require the multiple operations and systems required by prior art processes is needed. Further, a process to produce bicarbonate sorbent directly employed in the desulfurization of flue gases, that is efficient and economical, is needed.

SUMMARY OF THE DISCLOSURE

The subject system and method is a dry flue gas desulfurization system that uses dry sorbent injection of sodium bicarbonate for acidic gas (SO_2, SO_3, HCl, HF) removal from flue gas generated by a power plant or other industrial plant, with integrated sodium bicarbonate sorbent regeneration using a dual alkali process. Accordingly, the subject system uses an injector operable to inject a sorbent into a duct through which plant flue gas flows to a particulate collection device. By injecting sorbent directly into a duct with hot flue gas flow, capital and operational costs are significantly lower than that for other commercially available emission control systems. The injected sorbent efficiently achieves flue gas acid gas removal. Filters within a particulate collection device are used to collect spent sorbent, unused sorbent and particulates such as fly ash from flue gas flowing therethrough. An alkali reactor is used for reaction of the spent sorbent, unused sorbent and particulates collected in the particulate collection device, with lime, water and air to produce sodium hydroxide and gypsum. The produced gypsum may be discarded or used in the production of building materials. A carbon dioxide reactor is used to react the sodium hydroxide produced in the alkali reactor with flue gas carbon dioxide to produce sodium bicarbonate sorbent for injection. The reaction of sodium hydroxide with carbon dioxide produces sodium bicarbonate sorbent for use in the subject system. As such, sorbent cost for emissions control is significantly reduced.

The subject method of dry flue gas desulfurization uses semi-dry sorbent (in the form of a slurry) injection by injecting a sorbent into a duct through which plant flue gas flows. By injecting sorbent directly into a duct with hot flue gas flow, this method significantly reduces capital and operational costs over those of other commercially available emission control systems. The sorbent is injected into the flue gas duct for flue gas acid gas SO_2, SO_3, HCl, HF removal by the sorbent. Collecting spent sorbent, unused sorbent and other flue gas particulates such as fly ash is accomplished with filters within a particulate collection device. As such, spent sorbent, unused sorbent and flue gas particulates collected from the flue gas flowing through the particulate collection device may be used to regenerate the sorbent. Reacting the collected spent sorbent, unused sorbent and flue gas particulates with lime, water and air to produce sodium hydroxide and gypsum. The produced sodium hydroxide and gypsum are separable in a product separator, such as a hydrocyclone. The produced gypsum may be discarded or used in the production of building materials or the like. Reacting the produced sodium hydroxide with a relatively small slip stream of flue gas carbon dioxide produces sodium bicarbonate sorbent for injection. By regenerating the sodium bicarbonate sorbent through the subject method, sorbent cost for emissions control is significantly reduced.

In summary, the subject dry flue gas desulfurization system comprises an injector operable to inject a sorbent into a duct through which plant flue gas flows to a particulate collection device for flue gas acid gas removal by the sorbent, filters within the particulate collection device operable to collect spent sorbent from flue gas flowing therethrough, an alkali reactor operable for reaction of spent sorbent, lime, water and air to produce sodium hydroxide and gypsum, and a carbon dioxide reactor operable for reaction of sodium hydroxide with flue gas carbon dioxide to produce sodium bicarbonate sorbent for injection. The sorbent used and produced in this system is sodium bicarbonate. The particulate collection device uses filters that are fabric or electrostatic to collect the spent sorbent. The collected and reacted spent sorbent produces sodium hydroxide and gypsum separable in a product separator, such as a hydrocyclone. Optionally, in the production of the sorbent, the spent sorbent may be reacted with sulfuric acid prior to reaction with lime. Using the subject system, flue gas acid gas includes SO_2, SO_3, HCl and HF and removal includes desulfurization.

In summary, the subject method of dry flue gas desulfurization comprises injecting a sorbent into a duct through which plant flue gas flows to a particulate collection device for flue gas acid gas removal by the sorbent, collecting with filters within the particulate collection device spent sorbent from flue gas flowing therethrough, reacting spent sorbent, lime, water and air to produce sodium hydroxide and gypsum, and reacting sodium hydroxide with flue gas carbon dioxide to produce sorbent for injection. The sorbent for the subject method is sodium bicarbonate. The filters used in the particulate collection device are either fabric or electrostatic. The produced sodium hydroxide and gypsum are separable in a product separator, such as a hydrocyclone. Optionally, in the production of sodium bicarbonate, the spent sorbent may be reacted with sulfuric acid prior to reaction with lime. According to the subject method, flue gas acid gas includes SO_2, SO_3, HCl and HF and removal includes desulfurization.

Additional features and advantages of the subject disclosure will be readily apparent from the following detailed description in which preferred embodiments have been set forth in detail in conjunction with accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The subject disclosure will now be described in more detail with reference to the appended drawings in which:

FIG. **1** is a schematic view of a system according to one embodiment of the present invention;

FIG. **2** is a schematic view of a system according to another embodiment of the present invention; and

FIG. **3** is a schematic view of a system according to another embodiment of the present invention.

DETAILED DESCRIPTION

Referring now to the drawings in which like reference numerals indicate like parts, and in particular to FIG. **1**, wherein the subject dry flue gas desulfurization system **10** receives a flow of hot flue gas FG from a power or other industrial plant **12** fossil fuel or waste fuel combustion fired furnace or boiler **12***a*. The hot flue gas FG generated by the fossil fuel or waste fuel combustion fired furnace or boiler **12***a* comprises acid gases such as for example SO_2, SO_3, HCl and HF. The hot flue gas FG enters an injection duct **14** fluidly connected between furnace or boiler **12***a* and a particulate collector **16**. Sodium bicarbonate **18** from a sodium bicarbonate source **20** is transported via fluidly connected duct/pipe **22** to an injector **24** for dry or semi-dry sorbent injection (DSI), which injected sorbent can also be in a slurry form, into injection duct **14** and the flue gas FG flowing therethrough. Within injection duct **14**, the injected sodium bicarbonate **18** reacts with acid gases such as SO_2, SO_3, HCl and HF in the flue gas FG to remove the acid gases such as SO_2, SO_3, HCl and HF from the flue gas FG and produce reaction products **26**. For example, sodium bicarbonate reacts with flue gas FG SO_X according to the following reactions provided in equations EQ 1, EQ 2 and EQ 3 below.

$$2NaHCO_3\text{+Heat (from FG)}\rightarrow Na_2CO_3+H_2O+CO_2 \quad \text{(EQ 1)}$$

$$Na_2CO_3+SO_2\rightarrow Na_2SO_3+CO_2 \quad \text{(EQ 2)}$$

$$Na_2CO_3+SO_3\rightarrow Na_2SO_4+CO_2 \quad \text{(EQ 3)}$$

Flue gas FG having acid gases such as SO_2, SO_3, HCl and HF removed therefrom, flows from injection duct **14** into fluidly connected particulate collector **16**. Within particulate collector **16** at least a portion of the dry reaction products **26**, unreacted sodium bicarbonate and carbonate, and fly ash entrained in the flue gas FG is removed therefrom by filters **28** and collected in bottom hoppers **30**. The presence of unreacted sodium bicarbonate and carbonate mixed in with the filtered dry reaction products **26**, results in further capture of SO_2, SO_3, HCl and HF from the flue gas FG flowing through the filters **28** of particulate collector **16**. Typically, particulate collector **16** is a fabric filter with a plurality of filters **28**. However, as one skilled in the art will appreciate, other types of filtration systems and other types of filters or electrostatic precipitators may be utilized. So, in summary, sodium bicarbonate **18** is a freshly prepared slurry, which is injected into the system upstream of the particulate collector **16**. The sodium bicarbonate decomposes in the presence of the flue gas FG heat into sodium carbonate, carbon dioxide and water according to equation EQ 1. The sodium carbonate further reacts with the acidic gases and the reaction products along with the unreacted sodium bicarbonate **18** and sodium carbonate collected in the particulate collector **16**.

Dry reaction products **26**, such as sodium sulphite and sodium sulphate, with unreacted sodium bicarbonate, sodium carbonate and fly ash mixed therein, are transported from bottom hoppers **30** of particulate collector **16** to an alkali reactor **32** via ductwork/pipe **34** fluidly connected between bottom hoppers **30** and alkali reactor **32**. Additionally, lime **38** from a lime source **40** is supplied to alkali reactor **32** via a fluidly connected supply duct **42** therebetween. As an alternative, lime can also be supplied in the form of $Ca(OH)_2$. Air **44** from an air source **46** is supplied to alkali reactor **32** via an air pipe **48** fluidly connected between the air source **46** and alkali reactor **32**. Water **50** from a water source **52** is supplied to alkali reactor **32** via a water pipe **54** fluidly connected between the water source **52** and the alkali reactor **32**. Within alkali reactor **32**, dry reaction products **26**, unreacted sodium bicarbonate, sodium carbonate and fly ash, hereinafter referred to in combination as collection mixture **36** is reacted with the lime **38** and water **50** to produce sodium hydroxide **56** and calcium sulfite. Also, air **44** within alkali reactor **32** oxidizes the calcium sulphite to produce gypsum **58**, according to the following reactions provided in equations EQ 4 and EQ 5 below.

$$Na_2SO_4+CaO+H_2O \rightarrow 2NaOH+CaSO_4 \quad \text{(EQ 4)}$$

$$Na_2SO_3+CaO+H_2O+Air \rightarrow 2NaOH+CaSO_4 \quad \text{(EQ 5)}$$

The reaction products, sodium hydroxide **56** and gypsum **58**, are transported to a product separator **60**, such as a hydrocyclone. From the product separator **60**, the separated gypsum **58** is removed via port **64** and discarded or used, such as in the production of construction material. Sodium hydroxide **56** from the product separator **60** is transported to a carbon dioxide reactor **66** via a duct/pipe **68** fluidly connected between the product separator **60** and the carbon dioxide reactor **66**.

From particulate collector **16**, the cleaned flue gas CG flows to a stack **70** via a duct **72** fluidly connected between particulate collector **16** and stack **70** for release of the cleaned flue gas CG to the atmosphere. Additionally, air **44** from the alkali reactor **32** flows to duct **72** for release through stack **70** via duct **74** fluidly connected between alkali reactor **32** and duct **72**. A portion of the cleaned flue gas CG, approximately 15 percent or less, or approximately 10 percent or less, or approximately 5 percent or less, is diverted from duct **72** to the carbon dioxide absorber **66** via duct **76** fluidly connected between duct **72** and carbon dioxide absorber **66**. Within carbon dioxide absorber **66**, sodium hydroxide **56** from product separator **60** reacts with carbon dioxide present in the diverted cleaned flue gas CG to produce sodium bicarbonate **18**. The sodium bicarbonate **18** is produced according to the reaction set forth below in equation EQ 6.

$$2NaOH+2CO_2 \rightarrow 2NaHCO_3 \quad \text{(EQ 6)}$$

Sodium bicarbonate **18** produced in carbon dioxide absorber **66** is transported to sodium bicarbonate source **20** for use as needed in the dry flue gas desulfurization system **10** via duct **78** fluidly connected between carbon dioxide absorber **66** and sodium bicarbonate source **20**. In the sodium bicarbonate source **20**, dewatering equipment such as a hydrocyclone, belt filter, centrifuge, dryer, or the like, can be used to maintain the desired sodium bicarbonate concentration. Diverted cleaned flue gas CG flowing through carbon dioxide absorber **66** is transported to stack **70** via duct **76*b*** fluidly connected between carbon dioxide absorber **66** and stack **70**. Sodium bicarbonate source **20** may include a particulate separator **80**. Any unreacted sodium hydroxide **56** from particulate separator **80** may be returned to carbon dioxide absorber **66** via duct **82** fluidly connected between particulate separator **80** and carbon dioxide absorber **66**.

A method of using the dry flue gas desulfurization system **10** comprises injecting sodium bicarbonate **18** into a flue gas FG stream upstream of a particulate collector **16** to remove acid gases such as SO_2, SO_3, HCl and HF from the flue gas FG, reacting collection mixture **36** collected in the particulate collector **16** with lime **38**, air **44** and water **50** to produce sodium hydroxide **56** and gypsum **58**, reacting the produced sodium hydroxide **56** with carbon dioxide from a slip stream of the cleaned flue gas CG downstream of the particulate collector **16** to produce sodium bicarbonate **18** for injection into the system **10**.

Schematically illustrated in FIG. **2**, is another embodiment of the subject dry flue gas desulfurization system and method. The system illustrated in FIG. **2** has features in common with those illustrated in FIG. **1**. As such, features illustrated in FIG. **2** common to those of FIG. **1** are signified using the same reference numbers but with the number "2" preceding them.

Now referring to FIG. **2**, is another embodiment of the subject dry flue gas desulfurization system **210**. The subject dry flue gas desulfurization system **210** receives a flow of hot flue gas FG from a power or other industrial plant **212** fossil fuel or waste fuel combustion fired furnace or boiler **212*a***. The hot flue gas FG generated by the fossil fuel or waste fuel combustion fired furnace or boiler **212*a*** comprises acid gases such as for example SO_2, SO_3, HCl and HF. The hot flue gas FG enters an injection duct **214** fluidly connected between furnace or boiler **212*a*** and a particulate collector **216**. Sodium bicarbonate **218** from a sodium bicarbonate source **220** is transported via fluidly connected duct **222** to an injector **224** arranged upstream **214*a*** and/or downstream **214*b*** from an optional air preheater **214*c*** arranged within injection duct **214**. Sodium bicarbonate **218** is injected according to dry sorbent injection (DSI) by one or more injectors **224** into injection duct **214** and the flue gas FG flowing therethrough. As such, sodium bicarbonate **218** is injected into injection duct **214** in either dry form, semi-dry form or in slurry form. Within injection duct **214**, the injected sodium bicarbonate **218** reacts with acid gases such as SO_2, SO_3, HCl and HF in the flue gas FG to remove the acid gases such as SO_2, SO_3, HCl and HF from the flue gas FG and produce reaction products **226**. For example, sodium bicarbonate reacts with flue gas FG SO_X according to the following reactions provided in equations EQ 7, EQ 8 and EQ 9 below.

$$2NaHCO_3+\text{Heat (from FG)} \rightarrow Na_2CO_3+H_2O+CO_2 \quad \text{(EQ 7)}$$

$$Na_2CO_3+SO_2 \rightarrow Na_2SO_3+CO_2 \quad \text{(EQ 8)}$$

$$Na_2CO_3+SO_3 \rightarrow Na_2SO_4+CO_2 \quad \text{(EQ 9)}$$

Flue gas FG having acid gases such as SO_2, SO_3, HCl and HF removed therefrom, flows from injection duct **214** into fluidly connected particulate collector **216**. Within particulate collector **216** at least a portion of the dry reaction products **226**, unreacted sodium bicarbonate **218**, sodium carbonate and fly ash entrained in the flue gas FG is removed therefrom by filters **228** and collected in bottom hoppers **230**. The presence of unreacted sodium bicarbonate **218** mixed in with the filtered dry reaction products **226**, results in further capture of SO_2, SO_3, HCl and HF from the flue gas FG flowing through the filters **228** of particulate collector **216**. Typically, particulate collector **216** is a fabric filter with a plurality of filters **228**. However, as one skilled in the art will appreciate, other types of filtration systems and other types of filters or electrostatic precipitators may be utilized.

Dry reaction products **226**, such as sodium carbonate, sodium sulphite and sodium sulphate, with unreacted sodium bicarbonate **218**, sodium carbonate and fly ash mixed therein, are transported from bottom hoppers **230** of particulate collector **216** to a mixing tank **231** via ductwork **235** fluidly connected between bottom hoppers **230** and mixing tank **231**. Water **251** from a water supply **253** is supplied to mixing tank **231** via a water pipe **255** fluidly connected between the water supply **253** and the mixing tank **231**. The reaction products **226**, unreacted sodium bicarbonate, sodium carbonate and fly ash are mixed with water **251** in the mixing tank **231** to produce a moistened product or slurry **233**. The resultant moistened product or slurry **233** is transported to a product separator **261** such as a hydrocyclone via duct **263** fluidly connected between mixing tank **231** and product separator **261**. Within product separator **261**, the moistened product or slurry **233** is separated into a sodium sulfite and sodium sulfate portion **265** and a sodium carbonate portion **267**. The sodium carbonate portion **267** is transported via fluidly connected duct **271** and fluidly connected duct **268** to carbon dioxide absorber **266**. The sodium sulfite and sodium sulfate portion **265** is transported to an alkali reactor **232** via ductwork **269** fluidly connected between product separator **261** and alkali reactor **232**. Additionally, lime **238** from a lime source **240** is supplied to alkali reactor **232** via a fluidly connected supply duct **242** therebetween. As an option, air **244** from an air source **246** is supplied to alkali reactor **232** via an air pipe **248** fluidly connected between the air source **246** and alkali reactor **232**. Within alkali reactor **232**, the sodium sulfite and sodium sulfate portion **265** is reacted with the lime **38** and water **50** to produce sodium hydroxide **256**. In the reactor **232**, sodium sulphate and sodium sulphite is converted to calcium sulphate and calcium sulphite. Also, air **244** within alkali reactor **232** oxidizes some of the calcium sulphite to produce gypsum **258**, according to the following reactions provided in equations EQ 10 and EQ 11 below.

$$CaSO_3+1/2O_2 \rightarrow CaSO_4 \quad \text{(EQ10)}$$

$$Na_2SO_4+CaO+H_2O \rightarrow 2NaOH+CaSO_4 \quad \text{(EQ 11)}$$

From a port **264**, gypsum **258** is removed from the alkali reactor **232** and discarded or used, such as in the production of construction material. Sodium hydroxide **256** from the alkali reactor **232** is transported to a carbon dioxide absorber **266** via a duct **268** fluidly connected between the alkali reactor **232** and the carbon dioxide absorber **266**.

From particulate collector **216**, the cleaned flue gas CG flows to a stack **270** via a duct **272** fluidly connected between particulate collector **216** and stack **270** for release of the cleaned flue gas CG to the atmosphere. A portion of the cleaned flue gas CG, approximately 15 percent or less, or approximately 10 percent or less, or approximately 5 percent or less, is diverted from duct **272** to the carbon dioxide absorber **266** via duct **276** fluidly connected between duct **272** and carbon dioxide absorber **266**. Within carbon dioxide absorber **266**, sodium hydroxide **256** from alkali reactor **232** reacts with carbon dioxide **276*a*** present in the diverted cleaned flue gas CG to produce sodium bicarbonate **218**. The sodium bicarbonate **218** is produced according to the reaction set forth below in equation EQ 12.

$$2NaOH+2CO_2 \rightarrow 2NaHCO_3 \quad \text{(EQ 12)}$$

Sodium bicarbonate **218** produced in carbon dioxide absorber **266** is transported to sodium bicarbonate source **220** for use as needed in the dry flue gas desulfurization system **210** via duct **278** fluidly connected between carbon dioxide absorber **266** and sodium bicarbonate source **220**. Sodium bicarbonate source **220** may include a solid-liquid separator or dryer **280**. Any unreacted sodium hydroxide **256** from solid-liquid separator or dryer **280** may be returned to carbon dioxide absorber **266** via duct **282** fluidly connected between particulate separator **280** and carbon dioxide absorber **266**. Diverted cleaned flue gas CG flowing through carbon dioxide absorber **266** is transported to stack **270** via duct **276*b*** fluidly connected between carbon dioxide absorber **266** and stack **270**. Fluidly connected to duct **276*b*** is duct **268 *a***. Duct **268*a*** is fluidly connected between duct **276*b*** and alkali reactor **232**. Air **244** supplied to alkali reactor **232** flows through duct **268*a*** and into duct **276*b***. From stack **270**, diverted cleaned flue gas CG and air **244** from duct **276*b*** is released to the atmosphere.

A method of using the dry flue gas desulfurization system **210** comprises injecting sodium bicarbonate **218** into a flue gas FG stream upstream **214*a*** or downstream **214*b*** of an optional air preheater **214*c*** upstream of a particulate collector **216** to remove acid gases such as SO_2, SO_3, HCl and HF from the flue gas FG, mixing reaction products **226**, unreacted sodium bicarbonate, sodium carbonate and fly ash with water **251** to produce a moistened product or slurry **233**, separating the moistened product or slurry **233** into a sodium sulfite and sodium sulfate portion **265** and a sodium carbonate portion **267**, reacting the sodium sulfite and sodium sulfate portion **265** with air **244** and lime **238** to produce sodium hydroxide **256**, and reacting the sodium hydroxide **256** with carbon dioxide **276*a*** from diverted cleaned flue gas CG to produce sodium bicarbonate **218** for injection into the system **210**.

Schematically illustrated in FIG. **3**, is another embodiment of the subject dry flue gas desulfurization system and method. The system illustrated in FIG. **3** has features in common with those illustrated in FIG. **1**. As such, features illustrated in FIG. **3** common to those of FIG. **1** are signified using the same reference numbers but with the number "3" preceding them.

Now referring to FIG. **3**, is another embodiment of the subject dry flue gas desulfurization system **310**. The subject dry flue gas desulfurization system **310** receives a flow of hot flue gas FG from a power or other industrial plant **312** fossil fuel or waste fuel combustion fired furnace or boiler **312*a***. The hot flue gas FG generated by the fossil fuel or waste fuel combustion fired furnace or boiler **312*a*** comprises acid gases such as for example SO_2, SO_3, HCl and HF. The hot flue gas FG enters an injection duct **314** fluidly connected between furnace or boiler **312*a*** and a particulate collector **316**. Sodium bicarbonate **318** from a sodium bicarbonate source **320** is transported via fluidly connected duct **322** to an injector **324** for dry sorbent injection (DSI) into injection duct **314** and the flue gas FG flowing therethrough. As such, sodium bicarbonate **318** is injected into injection duct **314** in either dry form, semi-dry form or in slurry form. Within injection duct **314**, the injected sodium bicarbonate **318** reacts with acid gases such as SO_2, SO_3, HCl and HF in the flue gas FG to remove the acid gases such as SO_2, SO_3, HCl and HF from the flue gas FG and produce reaction products **326**. For example, sodium bicarbonate reacts with flue gas FG SO_X according to the following reactions provided in equations EQ 13, EQ 14 and EQ 15 below.

$$2NaHCO_3+\text{Heat (from FG)} \rightarrow Na_2CO_3+H_2O+CO_2 \quad \text{(EQ 13)}$$

$$Na_2CO_3+SO_2 \rightarrow Na_2SO_3+CO_2 \quad \text{(EQ 14)}$$

$$Na_2CO_3+SO_3 \rightarrow Na_2SO_4+CO_2 \quad \text{(EQ 15)}$$

Flue gas FG having acid gases such as SO_2, SO_3, HCl and HF removed therefrom, flows from injection duct **314** into fluidly connected particulate collector **316**. Within particulate collector **316** at least a portion of the dry reaction products **326**, unreacted sodium bicarbonate **318**, sodium carbonate and fly ash entrained in the flue gas FG is removed therefrom by filters **328** and collected in bottom hoppers **330**. The presence of unreacted sodium bicarbonate **318** mixed in with the filtered dry reaction products **326**, results in further capture of SO_2, SO_3, HCl and HF from the flue gas FG flowing through the filters **328** of particulate collector **316**. Typically, particulate collector **316** is a fabric filter with a plurality of filters **328**. However, as one skilled in the art will appreciate, other types of filtration systems and other types of filters or electrostatic precipitators may be utilized.

Dry reaction products **326**, such as sodium carbonate, sodium sulphite and sodium sulphate, with unreacted sodium bicarbonate **318**, sodium carbonate and fly ash mixed therein, are transported from bottom hoppers **330** of particulate collector **316** to a reaction tank **301** via ductwork **303** fluidly connected between bottom hoppers **330** and reaction tank **301**. Supplied to reaction tank **301** is sulfuric acid **305** from a sulfuric acid source **307** via duct **309** fluidly connected between sulfuric acid source **307** and reaction tank **301**. Water **311** from a water source **313** is supplied to reaction tank **301** via duct **315** fluidly connected between water source **313** and reaction tank **301**. Air **317** from an air source **319** is supplied to reaction tank **301** via duct **321** fluidly connected between air source **319** and reaction tank **301**. Dry reaction products **326**, such as sodium carbonate, sodium sulphite and sodium sulphate, with unreacted sodium bicarbonate **318**, sodium carbonate and fly ash mixed therein, react with the sulfuric acid **305**, water **311** and air **317** supplied to the reaction tank **301** to produce a moistened or a slurry of sodium sulfate **323**. The resultant moistened or slurry of sodium sulfate **323** is transported to an alkali reactor **332** via duct **301***a* fluidly connected between reaction tank **301** and alkali reactor **332**. Lime **338** from a lime source **340** is supplied to alkali reactor **332** via a fluidly connected supply duct **342** therebetween. Within alkali reactor **332**, sodium sulfate **323** reacts with the lime **338** to produce a product **332***a*. Product **332***a* is transported from alkali reactor **332** to a product separator **343** via duct **332***b* fluidly connected between the alkali reactor **332** and the product separator **343**. The product separator **343**, such as a hydrocyclone separates product **332***a* into sodium hydroxide **356** and gypsum **358**. Gypsum **358** is produced according to the following reaction provided in equation EQ 16 below.

$$Na_2SO_4+CaO+H_2O \rightarrow 2NaOH+CaSO_4 \quad \text{(EQ 16)}$$

From the product separator **343**, the separated gypsum **358** is removed via port **364** and discarded or used, such as in the production of construction material. Sodium hydroxide **356** from the product separator **343** is transported to a carbon dioxide absorber **366** via a duct **368** fluidly connected between the product separator **343** and the carbon dioxide absorber **366**.

From particulate collector **316**, the cleaned flue gas CG flows to a stack **370** via a duct **372** fluidly connected between particulate collector **316** and stack **370** for release of the cleaned flue gas CG to the atmosphere. Additionally, air **317** and produced carbon dioxide from reaction tank **301** flow into duct **372** via duct **301***b* fluidly connected between reaction tank **301** and duct **372**. Via duct **372**, air **317** and produced carbon dioxide from reaction tank **301** are likewise released to the atmosphere via stack **370**. A portion of the cleaned flue gas CG, approximately 15 percent or less, or approximately 10 percent or less, or approximately 5 percent or less, is diverted from duct **372** to the carbon dioxide absorber **366** via duct **376** fluidly connected between duct **372** and carbon dioxide absorber **366**. Within carbon dioxide absorber **366**, sodium hydroxide **356** from product separator **343** reacts with carbon dioxide **376***a* present in the diverted cleaned flue gas CG to produce sodium bicarbonate **318**. The sodium bicarbonate **318** is produced according to the reaction set forth below in equation EQ 17.

$$2NaOH+2CO_2 \rightarrow 2NaHCO_3 \quad \text{(EQ 17)}$$

Sodium bicarbonate **318** produced in carbon dioxide absorber **366** is transported to sodium bicarbonate source **320** for use as needed in the dry flue gas desulfurization system **310** via duct **378** fluidly connected between carbon dioxide absorber **366** and sodium bicarbonate source **320**. Sodium bicarbonate source **320** may include a particulate separator **380**. Any unreacted sodium hydroxide **356** from particulate separator **380** may be returned to carbon dioxide absorber **366** via duct **382** fluidly connected between particulate separator **380** and carbon dioxide absorber **366**.

A method of using the dry flue gas desulfurization system **310** comprises injecting sodium bicarbonate **318** into a flue gas FG stream upstream of a particulate collector **316** to remove acid gases from the flue gas FG, reacting dry reaction products **326** with unreacted sodium bicarbonate **318** and fly ash collected in the particulate collector **316** with sulfuric acid **305**, water **311** and air **317** to produce a moistened or a slurry of sodium sulfate **323**, reacting the moistened or slurry of sodium sulfate **323** with lime **338** to produce sodium hydroxide **356** and gypsum **358** separated in a product separator **343** such as a hydrocyclone, reacting the sodium hydroxide **356** with carbon dioxide **376***a* from the cleaned flue gas CG downstream of the particulate collector **316** to produce sodium bicarbonate **318** for injection into the system **310**.

The above described embodiments for a dry flue gas desulfurization system **10**, **210**, **310** and the methods of using the same, provide many advantages in the reduction of harmful acid gas emissions. The dry sorbent injection (DSI) of sodium bicarbonate **18**, **218**, **318** directly into a duct **14**, **214**, **314** is relatively simple in comparison to alternative emissions control technologies. In particular, DSI is comparatively less capital cost intensive and at least equally if not more efficient in meeting emissions standards. Additionally, by reproducing the spent sodium bicarbonate **18**, **218**, **318** the system **10**, **210**, **310** is also comparatively more economical based on its relatively low operating and maintenance costs. As such, the subject dry flue gas desulfurization system **10**, **210**, **310** and method of using the same is a relatively low cost and relatively easy-to-use technology for utility plant, waste-to-energy plant and other industrial plant emissions control.

The invention claimed is:

1. A dry flue gas desulfurization system comprising:
- an injector operable to inject a sorbent into a duct through which plant flue gas flows to a particulate collection device for flue gas acid gas removal by the sorbent;
- filters within the particulate collection device operable to collect spent sorbent from flue gas flowing therethrough;
- an alkali reactor operable for reaction of spent sorbent, lime, water and air to produce sodium hydroxide and gypsum; and
- a carbon dioxide absorber operable for reaction of sodium hydroxide with flue gas carbon dioxide to produce sorbent for injection.

2. The system of claim **1**, wherein the sorbent is sodium bicarbonate.

3. The system of claim **1**, wherein the filters are fabric or electrostatic.

4. The system of claim **1**, wherein the produced sodium hydroxide and gypsum are separated in a product separator.

5. The system of claim **1**, wherein the produced sodium hydroxide and gypsum are separated in a hydrocyclone.

6. The system of claim **1**, wherein the spent sorbent is reacted with sulfuric acid prior to reaction with lime.

7. The system of claim **1**, wherein flue gas acid gas removal includes desulfurization.

8. The system of claim **1**, wherein flue gas acid gas removal includes SO_2, SO_3, HCl and HF.

9. A method of dry flue gas desulfurization comprising:

injecting a sorbent into a duct through which plant flue gas flows to a particulate collection device for flue gas acid gas removal by the sorbent;

collecting with filters within the particulate collection device spent sorbent from flue gas flowing therethrough;

reacting spent sorbent, lime, water and air to produce sodium hydroxide and gypsum; and

reacting sodium hydroxide with flue gas carbon dioxide to produce sorbent for injection.

10. The method of claim 9, wherein the sorbent is sodium bicarbonate.

11. The method of claim 9, wherein the filters are fabric or electrostatic.

12. The method of claim 9, wherein the produced sodium hydroxide and gypsum are separated in a product separator.

13. The method of claim 9, wherein the produced sodium hydroxide and gypsum are separated in a hydrocyclone.

14. The method of claim 9, wherein the spent sorbent is reacted with sulfuric acid prior to reaction with lime.

15. The method of claim 9, wherein flue gas acid gas includes SO_2, SO_3, HCl and HF and removal includes desulfurization.

* * * * *